NASA Glenn Aeronautics

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National Aeronautics and Space Administration

ARMD Strategic Thrusts

3 Mega-Drivers

6 Strategic Research & Technology Thrusts

Safe, Efficient Growth in Global Operations

- Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

Innovation in Commercial Supersonic Aircraft

- Achieve a low-boom standard

Ultra-Efficient Commercial Vehicles

- Pioneer technologies for big leaps in efficiency and environmental performance

Transition to Low-Carbon Propulsion

- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Real-Time System-Wide Safety Assurance

- Develop an integrated prototype of a real-time safety monitoring and assurance system

Assured Autonomy for Aviation Transformation

- Develop high impact aviation autonomy applications

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ARMD Programs

Mission Programs

Airspace Operations and Safety Program (AOSP)

- Safe, Efficient Growth in Global Operations
- Real-Time System-Wide Safety Assurance
- Assured Autonomy for Aviation Transformation

Advanced Air Vehicles Program (AAVP)

- Ultra-Efficient Commercial Vehicles
- Innovation in Commercial Supersonic Aircraft
- Transition to Low-Carbon Propulsion
- Assured Autonomy for Aviation Transformation (future)

Integrated Aviation Systems Program (IASP)

- Flight Research-Oriented Integrated, System-Level R&T supporting all six thrusts
- X-Planes/Test Environment

Seedling Program

Transformative Aeronautics Concepts Program (TAC)

- High-risk, leap-frog ideas supporting all six thrusts
- Critical cross-cutting tool and technology development
- Assured Autonomy for Aviation Transformation

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Electrified Aircraft Propulsion

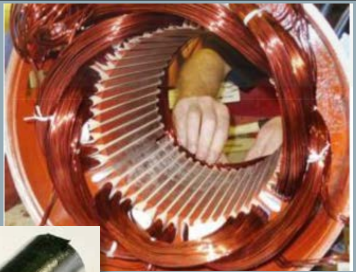
New Concept

Electrically driven propulsion system with electricity generated from gas turbine engine cores or alternative energy sources like batteries.

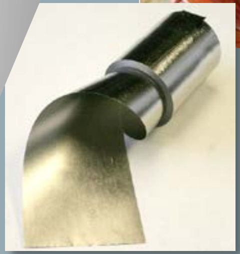
Advanced 150-passenger aircraft concept with electric propulsion offering 12% reduction in fuel burn.

Key Technologies:

- Lighter motors with higher power, generators, and power control systems
- Lightweight, high voltage electrical power transmission cables & insulation



High power density electric motor



Advanced magnetic materials

Unique facilities at GRC:

- Megawatt level electric test bed
- Altitude chamber for testing high voltage machines

Flight demonstrations of advanced technologies

Goal: Flight tests, ground demo’s and technology readiness by 2025 to support 2035 Entry into Service

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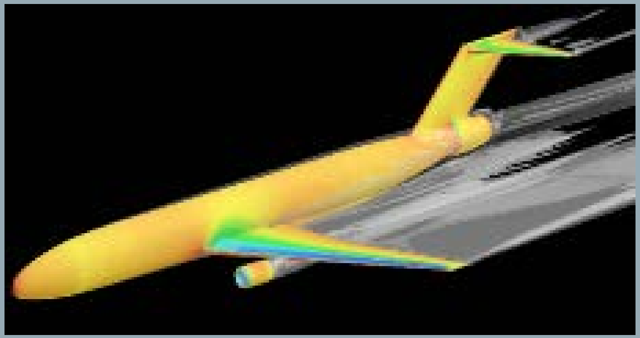
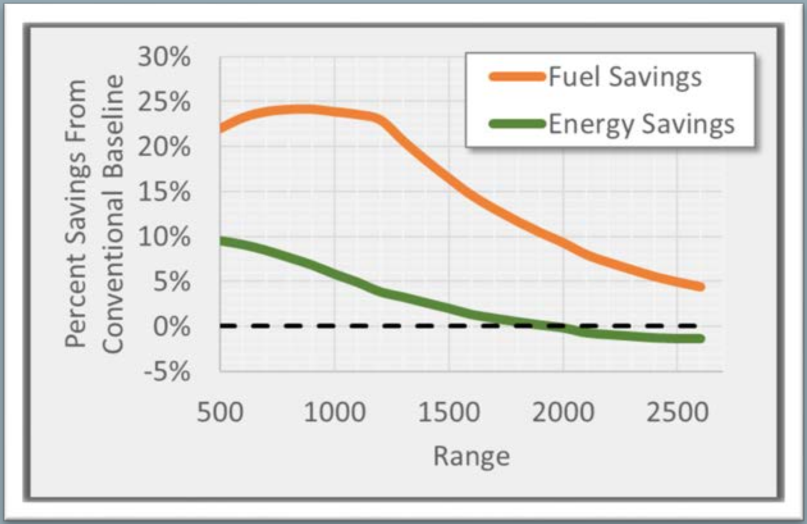
Propulsion System Conceptual Design

Parallel hybrid conceptual designs established





- **Two NRA concept designs incorporating parallel hybrid found 900 nm (economic mission) solutions with 6 to 24% fuel reduction and 2.5 to 7% net energy savings.**
- **Turboelectric with aft fuselage boundary layer ingestion concept provided 7-12% fuel reduction for 900-3500 nm missions with net energy savings**

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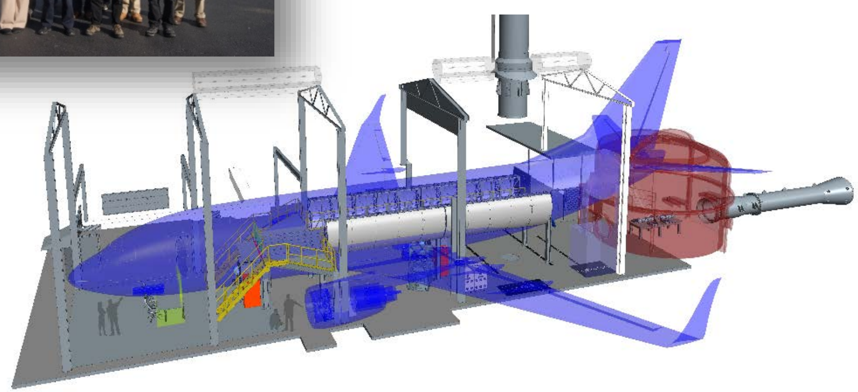
NASA Electric Aircraft Testbed

12 MW Input Power
1 MW Cooling
1 MW Reactor Load

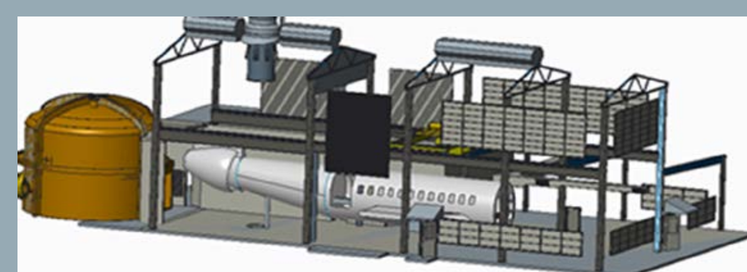


Relevant Test Capabilities

In FY16, completed testbed design and successful operation of the single-string 125kW powertrain (NEAT)

Full multi-MW capability by FY19

Power	Cooling	Safety	Expansion	Altitude
Up to 12MW	Chillers and LH2 Storage	Remotely located	Wall Extension	Flight Conditions



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Advanced Aircraft Propulsion

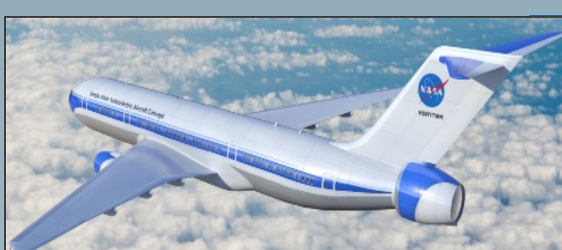
NASA has aggressive goal of reducing aircraft fuel/energy consumption by 50-60% in the mid-term (2025-35) and 60-80% in the long-term (beyond 2035).

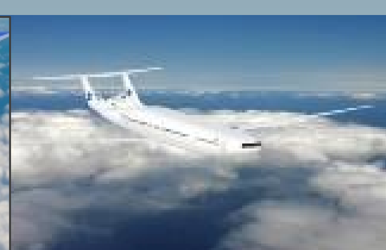
New Concept: Boundary Layer Ingestion

Embedding engines inside the wing or fuselage energize aircraft boundary layers reducing drag and increasing propulsive efficiency.

“Boundary Layer Ingesting” Propulsion systems reduce fuel burn by 5 to 10%.

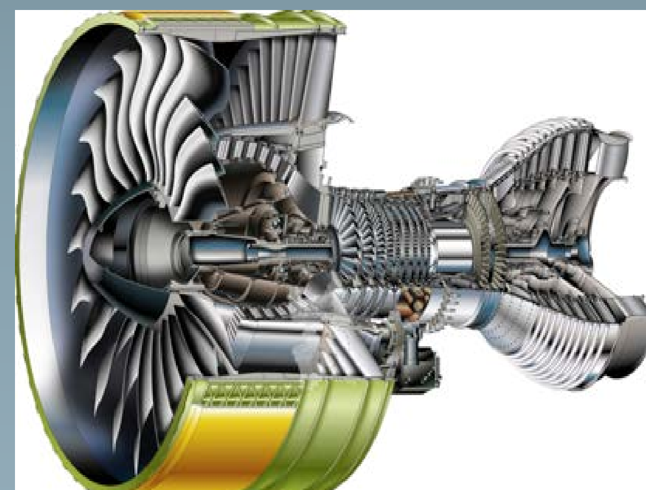
New fuel-efficient aircraft concepts enabled by boundary layer ingestion





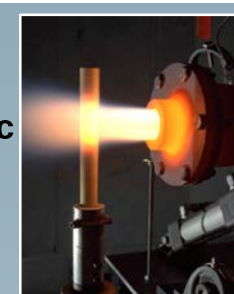
Revolutionizing Gas Turbine Propulsion

Gas turbine engines can be more efficient with GRC’s technologies and partnerships with industry.



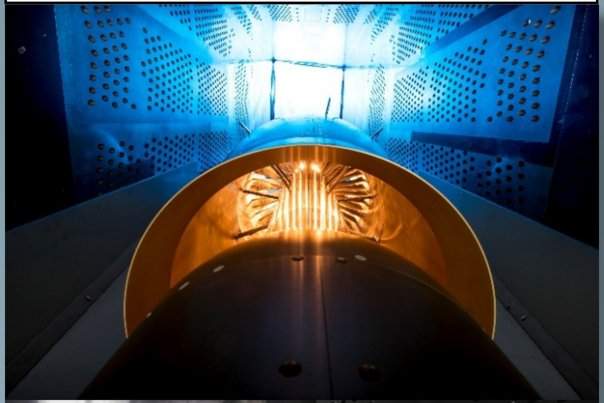
Additive manufacturing creating new opportunities for all engine components

Lower aerodynamic losses and new cooling methods



High temperature materials key to enabling higher efficiencies

BLI2DTF Test



Objective

- Demonstrate boundary layer ingesting (BLI) distortion tolerant fan performance, operability, and structural characteristics at cruise conditions

Approach

- Design and fabricate a scale-model, boundary layer ingesting fan system with inlet and 22” distortion-tolerant fan
- Conduct cruise performance test in the NASA GRC 8’x6’ wind tunnel to demonstrate system level benefits of BLI propulsion

Status

- Entire planned test matrix to meet minimum success criteria completed
  - Fan mapping at design Mach number, including high resolution pressure and temperature measurements in the inlet and behind the fan exit guide vanes
  - Additional stall data was collected at fan design speed
  - Limited data on performance sensitivities to bleed and Mach number variations were also obtained

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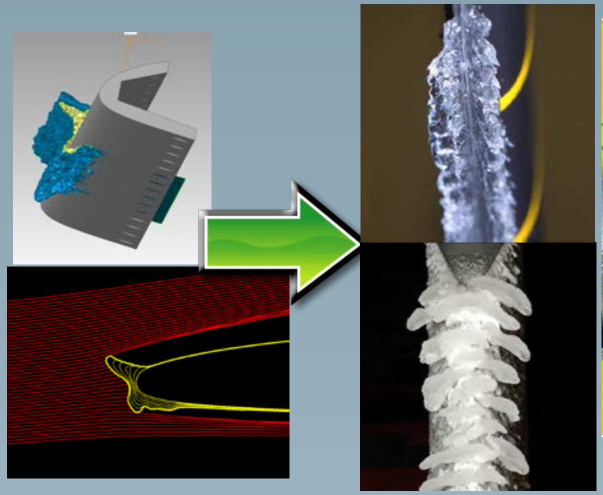
Engine and Aircraft Icing

Leading international research on aircraft and engine icing to increase aircraft safety.

- **Characterization of the icing environment**
- **Impact of icing on aircraft aerodynamics and engine performance**
- **Simulation of ice growth on aircraft using wind tunnels and computational models**
- **Development of icing protection technology**

Engine in ice crystal cloud

Testing in Icing Research Tunnel



Simulation of icing using computational models

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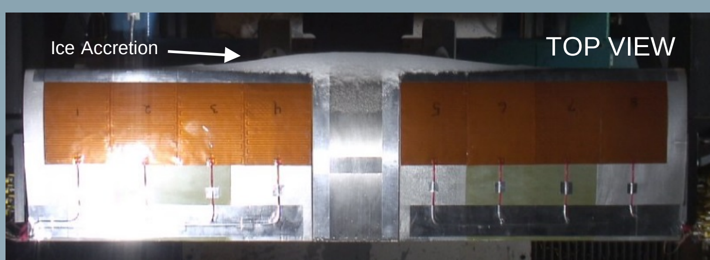
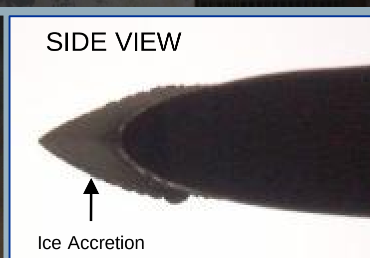
Propulsion Icing Capability

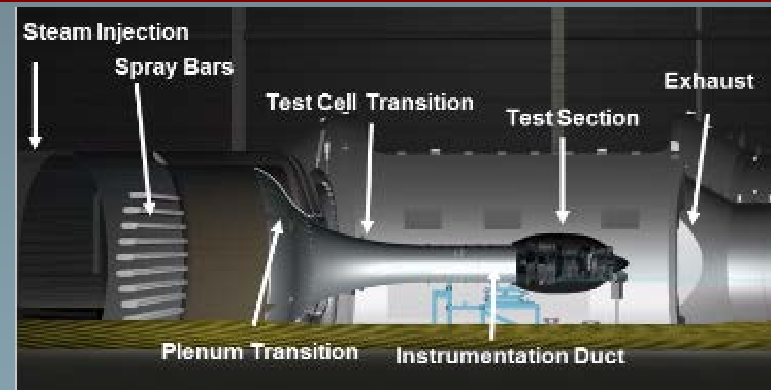
Demonstrated capability to conduct fundamental ice crystal physics studies in PSL

Research airfoil along with temperature and humidity measurement probes

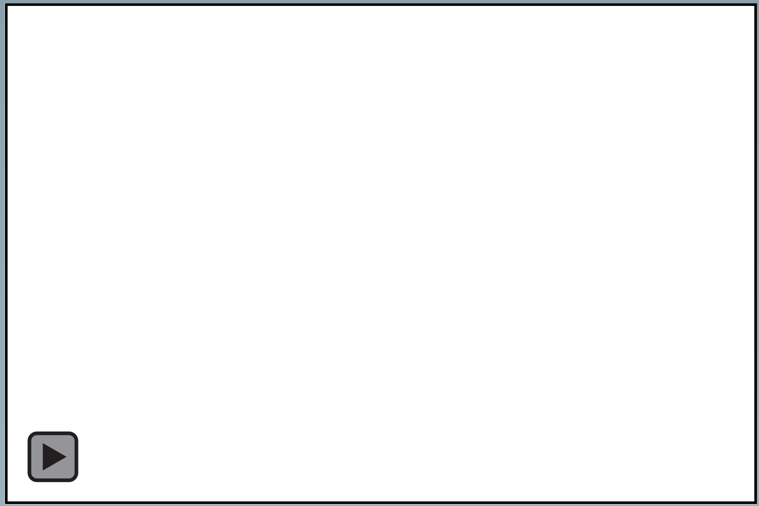




Dataset to develop in-house icing prediction/risk codes using Honeywell LF11



PSL Facility Layout



Ice Accretion Downstream of Exit Guide Vanes (Flow is going right to left)

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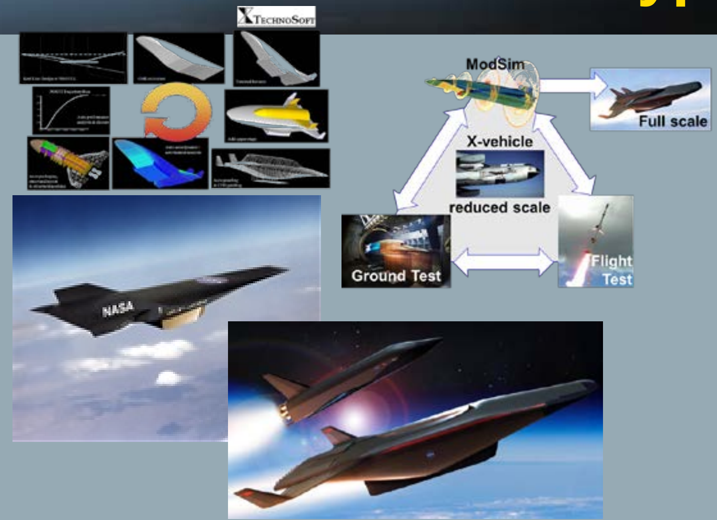
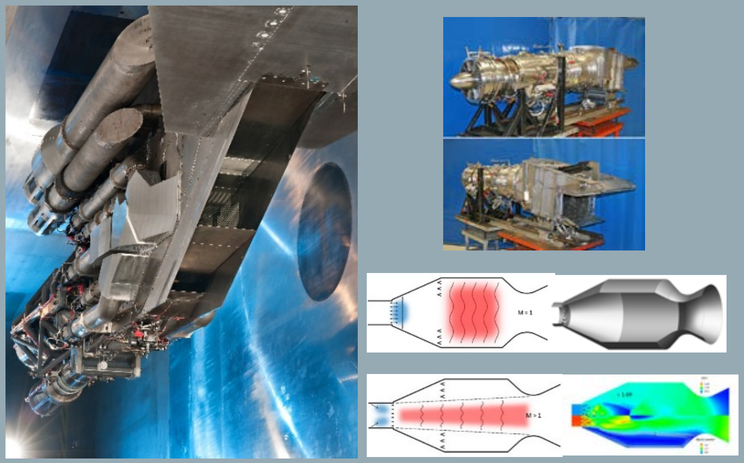
Hypersonic Technology

Performing fundamental research in and developing tools & technologies for - Affordable, Reusable, Air-Breathing Hypersonic Propulsion and Vehicle Systems:

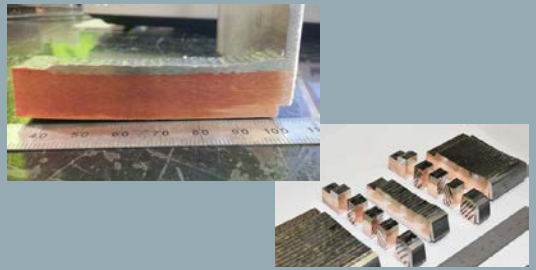
- **Propulsion Systems Analysis**
- **Combined Cycle Mode Transition – Performance, Operability, and Controls**
- **Advanced Sensors for Adaptive Control and Health Monitoring**
- **Advanced Propulsion and Control Surface Seals Technologies**
- **Additively Manufactured Materials for Hypersonic Propulsion Systems**



Propulsion Systems Analysis

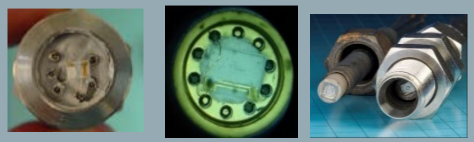


Combined Cycle Engine Research



Additive Manufacturing Research

High Temperature Seals Research & Development



Advanced Sensor Research & Development

Goal: Reusable propulsion and vehicle technologies to overcome critical barriers to achieving affordable, reusable hypersonic flight.

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CCE-LIMX Phase 3C Testing

Objective of Phase 3C Testing

✓ Phase 3B (December, 2015 – January, 2016)
- Characterize alternate inlet mode transition sequences at Mach 2.5 & 3.0
- Demonstrate closed loop control at Mach 3.0, 2.5, and accelerating mode transition (M2.5 →3.0)

Results:

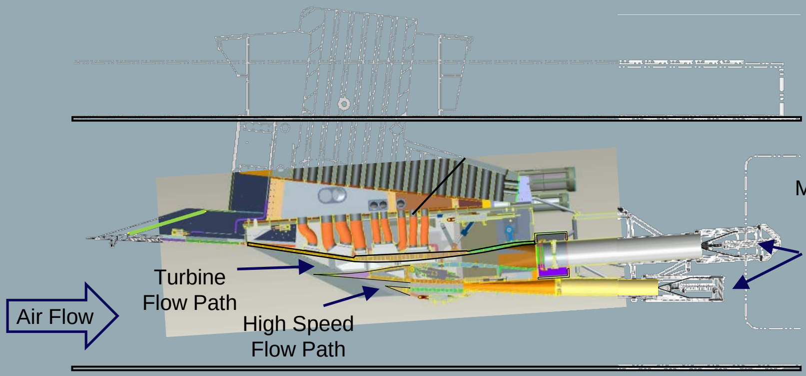
- Mach 3 Closed Loop Mode Transition (MT) - Low Q configuration w/o Active Engine Sim
- Mach 2.5 High Q Closed Loop MT (w/o Active Engine Sim)
- Demonstrated Active Engine Sim
- Characterization
  - Unstart Data to build Unstart Detection Algorithm
  - HS Flowpath Unlit Schedule
  - Mach 2.5 Alternate Ignition Configuration
- Controls
  - Developed nominal startup procedure
  - Demonstrated 'Pause' feature during MT (will be necessary to let engine idle before shutting off during MT)
  - Demonstrated Linear Interpolation
  - Developed testing efficiency upgrades to software
  - Developed a number of software and procedural upgrades for CIR as a result of mishap investigation

Phase 3C Configuration to simulate turbine engine

Turbine engine to be used in Phase 4

Postponed objectives:

- Closed Loop MT w/ Active Engine Sim (The Moon Rock)
- Mach 3 High Q data
- Accelerating Mode Transition Data
- Propulsion Cycle operation



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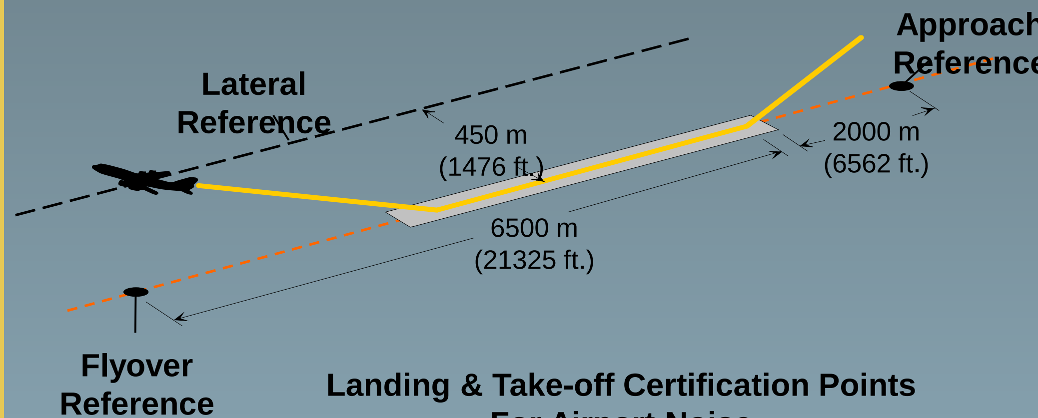
Commercial Supersonic Technology

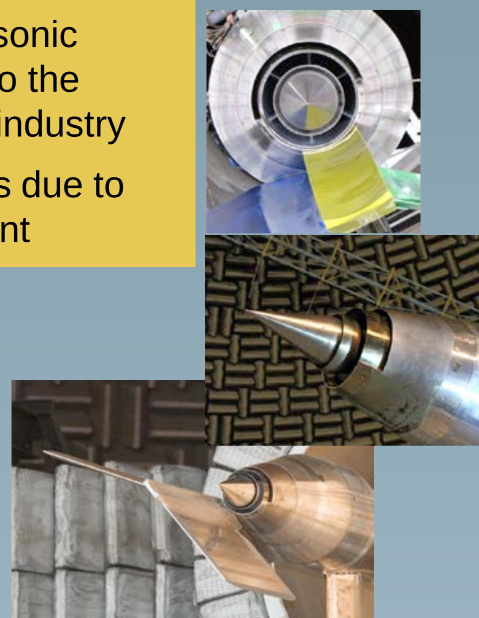
Supersonic transport can be a game changer for transcontinental and intercontinental flight and an opportunity for continued US leadership in aviation

- Working with industry and providing data to the FAA and International Civil Aviation Organization (ICAO) so regulations on Airport Noise and High Altitude Emissions that allow for supersonic flight can be established
- Technologies for Reduction of Supersonic Aircraft Airport Noise to levels close to the existing commercial subsonic airline industry
- Understanding of impact of emissions due to the proposed flight altitude is important



Landing & Take-off Certification Points For Airport Noise

Advanced Supersonic Transport Concept



Low Noise Supersonic Nozzles at GRC's AAPL

Low Boom Flight Demonstration Concept tested at GRC's 8x6 SWT

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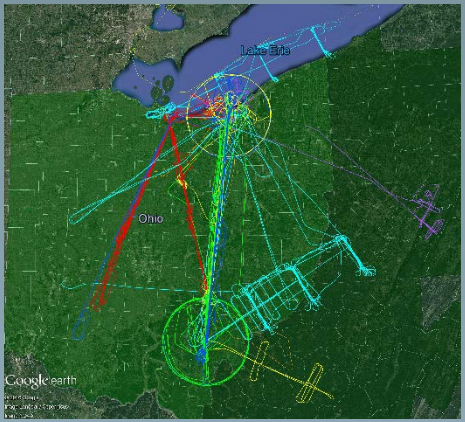
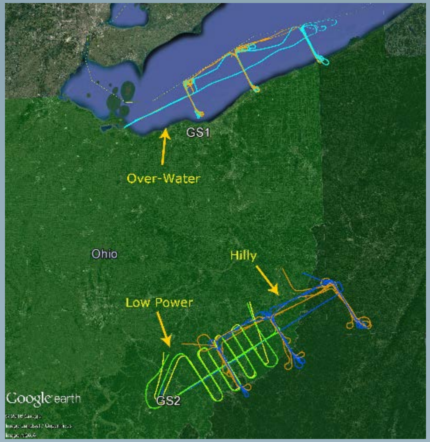
Aeronautical Communication System Architectures

Reduce technical barriers associated with integrating Unmanned Aircraft Systems (UAS) into the National Aerospace System (NAS) utilizing integrated system level tests in a relevant environment.

Terrestrial: Prototype Control and Non-Payload Communications (CNPC) radios will be used to validate Minimum Operational Performance Standards (MOPS).

Satellite: Development and evaluation of a “flexible” prototype unit and C2 test environment system to verify and validate the UAS SatCom Minimal Operation Performance Standards





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Upcoming in FY17 & FY18

- Aerodynamic and PAI testing of Low Boom Flight Demonstrator concept in 8’x6’ Supersonic Wind Tunnel.
- Development and Testing of High Temperature Material for Turbine Engines to enable reduction in fuel burn.
- Demonstrated two-speed drive system for rotorcraft with 50% improvement in efficient operational capability.
- Completion of Acoustic Upgrade to 9’x15’ Subsonic Wind Tunnel
- Testing of N+3 low-emission, fuel-flexible (LE-FF) combustor concept for emission reduction to 80% below CAEP6
- Engine Icing Test with Honeywell
- Subscale prototypes tested to establish design feasibility of 1MW power inverter, and 1 MW electric motor
- Command & Control Ku Band Communication Interference flight tests for UAS in the NAS.
- CCE-LIMX Phase 4 Testing at 10x10 SWT


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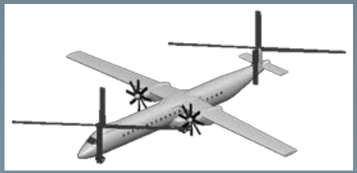
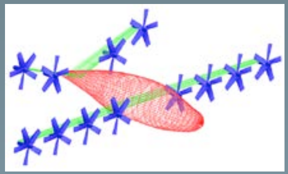
Vertical Lift Technology

Overcome significant barriers of vertical lift vehicles

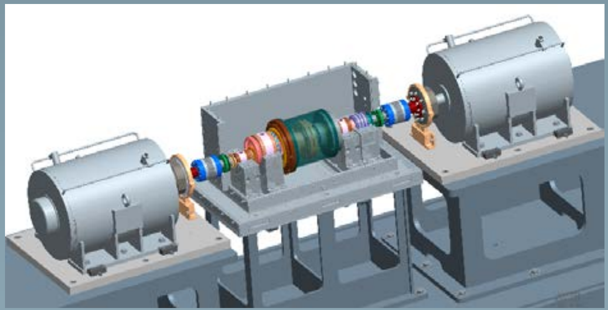
- **Efficient propulsion configurations that reduce fuel burn and gas emissions**
- **Leadership in technologies that improve speed, safety, mobility and payload**
- **Commercial vertical lift concepts with flight speeds required for insertion in the NextGen airspace**
- **Develop and demonstrate advanced, innovative propulsion components and systems**

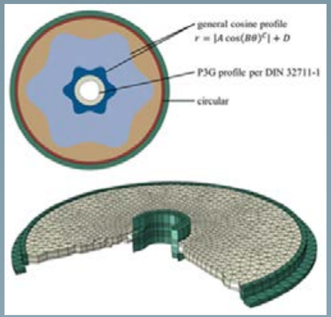




Variable Speed Transmission Test Rig

Vibration Reduction on Hybrid Gears





Variable Speed Power Turbine Performance Testing

High Efficiency Gas Generators

Wide Incident-Tolerant Blade Test

Ice Shedding on Rotor Blades